DIFFERENCE IN SOIL FORMATION BENEATH SPRUCE AND OAK FORESTS IN THE NORTHWESTERN USSR

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A study of the present day soil processes taking place beneath the forest cover is extremely important for resolving many scientific and practical problems of soil science and forestry. Bearing in mind that comparatively little study has been made of the forest soils of the western regions of the European USSR, we conducted a study of soils beneath broadleaf and coniferous forests in the Lithuanian SSR in 1962-1963. The purpose of this study, which was under the direction of Professor S. V. Zonn, was to determine the influence of these forests on the direction of the present day soil processes. It was assumed that under these physico-geographical conditions soils of a podzolic type are formed in most cases beneath both the broadleaf and coniferous tree stands. Differences were established only in the degree of development of the podzol formation process. Moreover, several investigators [3, 4, 5, 6, 8] under climatic conditions similar to ours and under those even more continental, separate the Brown Forest soils beneath broadleaf and coniferous—broadleaf forests. This fact plus the indication or hint by M. V. Vaychis [1] that there exist in Lithuania soils which have no signs of podzolization and which are similar to soils of the Brown-Earth type of soil formation beneath larch plantations under analogous natural conditions, have posed a problem for us — namely, to verify the earlier ideas concerning the direction of soil formation in the samples which we are studying.

This article presents certain data on the soil profile, its physico-chemical properties, and the processes which determine them beneath oak and spruce associations growing under similar natural conditions.

A study of the soils was made on the Central Lithuanian lowlands with absolute heights of not more than 50-80 m. The climate is transitional between the maritime climate of Western Europe and the continental climate of Eurasia. The mean annual air temperature and the annual precipitation are +6.2 C and 573 mm, respectively. Sixty-75% of the total annual precipitation occurs during the warm period (between April and October).

In order to explain the influence of the tree stand on soil formation a 2-year investigation was made on two permanent experimental plots laid out on the Kedaynyayskiy Forest. The distance between these plots was not more than 0.5 km.

The experimental plot No. 1 was laid out in a spruce stand containing oak, filbert and mixed grasses (Compartment 48). The density of the tree stand is 0.9, age 70 years. The composition is 6 spruce and 4 oaks, with occasional birch and ash. A sparse regrowth consisting of spruce, oak and ash. Filbert is predominant in the undergrowth. The grass cover is quite poorly developed (the degree of cover 50%). The grass cover is made up of Galeobdolon luteum Huds., starwort lanceolate (Stellaria holostea L.), Oxalis acetosella L., European wild ginger or asarum europeanum (Aegopodium podagraria L.), and forest strawberry (Fragaria vesca L.). The moss cover is not developed. The grass reserve during its maximum development amounted to 63.4 kg of absolutely dry matter per ha.

The soil forming parent material is a carbonate moraine sandy loam underlain at a depth of 1.5 m by a carbonate coarse clay loam stratified moraine. The soil is characterized by the following morphological profile:

A_0	0-2 cm	Semidecomposed coniferous needles, small oak branches and leaves, brown.

A_1	2-17 cm	Dark gray, becoming lighter with depth, with slight siliceous sprinkling in the upper part, sandy loam, friable, unstably blocky, densely pierced or riddled with roots of woody and grassy vegetation, fresh. Transition quite clear.
A_2	17-27 cm	Light gray, sandy loam, friable, structureless, fresh. Many roots. Transition gradual.
A_2B	27-40 cm	Pale yellow-brown, fresh, friable, sandy loam, with individual rust spots. Many roots. Transition gradual.
B_1	46-65 cm	Yellow-brown, compacted, coarse clay loam, nutty-slightly prismatic, fresh. Small rust spots and occasional roots found. Transition marked.
BC_{Ca}	65-130 cm	Red-brown, fresh, sandy loam, severely cemented with carbonates. Boulders and rubble are found. Roots are observed only in the upper part of the horizon. Transition gradual.
BC_{Ca}	130-145 cm	Yellow-brown, sandy loam, with red-brown lenses of coarse clay loam, compact-like, moist, cemented by carbonates. Traces of gleying in spots. Transition marked.
CD_{Ca}	145-180 cm and below	Red-broan, moist, coarse clay loam, structureless-lumpy, thickly cemented with carbonates. Many small stones.

A weak effervescence from 10% HCl begins at a depth of 65 cm.

Experimental plot No. 2 was laid out 500 m from experimental plot No. 1 (Compartment 43). A goutweed oak stand. Density of the tree stand is 0.8-0.9, age 110-120 years, site quality II, composition 9 oak and 1 spruce. Second growth of average density and made up of spruce and occasional ash and oak. The sparse undergrowth consists of filbert, alder buckthorn and Salix Caprea. The degree of grass cover is 80%, with a predominance of goutweed (Aegopodium podagraria L.) and Galeobdolon luteum Huds. The reserve is 276 kg of absolutely dry mass per ha.

The soil forming parent materials are the same as in experimental plot No. 1.

The soil is characterized by the following morphological features:

A_0	0-1 cm	Semidecomposed oak leaves with a slight admixture of spruce needles.
A_1	1-20 cm	Dark gray with a brownish tinge and with a barely noticeable siliceous sprinkling, sandy loam, friable, blocky-granular, fresh, generously riddled by roots. Transition difficult to distinguish by color.
A_1/A_2	20-30 cm	Gray, sandy loam, unstable clods, friable, fresh. Many roots. Transition gradual.
A_2B	30-43 cm	Yellow-brown with pale yellow tinge, fresh, friable, sandy loam, vaguely nutty-prismatic. Many roots. Transition marked.
B_1	43-60 cm	Brownish-red with occasional rust spots, compacted, fresh, coarse clay loam, nutty—slightly-prismatic. Occasional roots found. Transition gradual.
BC_{Ca}	60-125 cm	Red-brown, sandy loam, compacted and cemented with carbonates, moist. Many lime carbonate and noncarbonate boulders. Occasional roots found in the upper part of the horizon. Traces of slight gleying noted in the lower part. Transition gradual.
CD_{Ca}	125-160 cm and below	Red-brown, compact, moist, severely cemented with carbonates, coarse clay loam. Gleying poorly pronounced.

Effervescence from 10% HCl at a depth of 60 cm.

Table 1 — Particle-size composition of soil, % by weight

Number of experimental plot and forest type	Horizon	Depth, cm	Loss from HCl pretreatment, %	Particle diameter, mm						
				1-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	< 0.001	Total < 0.01
1. Spruce with oak-filbert-mixed grasses	A_1	2-10	3.04	22.63	35.68	17.30	4.86	3.91	12.58	21.37
	A_2	17-27	1.01	15.71	47.82	20.15	8.87	0.77	5.67	15.31
	A_2B	30-40	1.07	18.70	43.02	21.00	9.18	0.69	6.34	16.21
	B_1	45-55	1.88	9.16	48.36	18.92	5.78	1.21	14.70	21.69
	BC_{Ca}	85-95	5.95	15.50	36.68	25.01	3.82	4.86	8.17	16.86
	BC_{Cag}	130-140	5.39	37.20	43.95	3.42	3.93	2.05	4.08	10.00
	C_{Ca}	150-160	6.02	21.61	33.57	15.40	8.67	3.63	10.40	22.70
2. Goutweed-oak	A_1	5-15	1.88	20.05	42.49	18.50	4.67	5.23	7.18	17.08
	A_1/A_2	20-30	1.29	21.20	52.54	11.01	4.45	1.86	7.65	13.96
	A_2B	32-42	1.25	18.08	45.89	18.70	5.04	1.01	10.03	16.08
	B_1	45-55	5.01	13.25	28.69	30.06	4.68	0.61	17.70	22.99
	BC_{Ca}	70-80	6.99	25.95	34.31	20.05	2.62	2.02	8.06	12.70
	BC_{Ca}	110-120	7.42	24.70	33.27	18.20	2.94	4.46	9.01	16.41
	C_{Ca}	140-150	6.85	1.15	36.88	35.00	6.82	3.47	10.03	20.12

There are considerable differences in the make-up of the soils. For example, a fairly thick (15 cm) and dark colored humus horizon beneath the spruce stand with oak is replaced by a clearly pronounced podzolic horizon (A_2 horizon).

The podzolic horizon beneath the oak forest is practically undeveloped and, in addition, the thickness of the humus-accumulative horizon in this soil is considerably greater. The lowerlying horizons differ little from one another except that the soil beneath the spruce stand with oak is more noticeably gleyed in the lower part of the profile than that beneath the oak. In the oak stand the carbonates begin 5 cm higher than in the spruce. If the soil under spruce stand resembles soils of the Sod Podzolic type, the soil beneath oak possesses several features which are atypical of them. For example, (i) a clearly pronounced podzolic horizon is absent in the soil beneath oak; (ii) brown tones throughout the entire profile are predominant with a gradual transition of horizons; and (iii) the soil beneath oak has a thicker and a clearly pronounced humus-accumulative horizon with a blocky-granular structure. It should be noted that the soil under oak stand is very similar in morphology to the Brown Forest soils of Belorussia [4, 5], and Poland [8] and to the Lessivage Brown soils of France [7].

In particle-size composition (Table 1), the soils are quite similar. They are both formed on poorly pronounced binary deposits: sandy loam on top with carbonate moraine clay loam below. The removal of clay fraction from the upper horizons of the soils is expressed almost identically. The transition between horizons for the soil beneath oak is more gradual with respect to the clay fraction content than that beneath spruce with oak.

The determination of certain physical properties of the soil (Table 2) agrees well with the changes in particle-size composition and the humus content (Table 6). The bulk density in the upper horizons of the soil beneath the oak stand is less than that beneath the spruce, which correspondingly affects total porosity. The differences in these soil properties are probably due to the difference in the composition of the tree stands. The influence of the tree stands can be seen in the quantity and quality of the litterfall as well as in the character of distribution and mass of the root systems.

In the spruce stand the root mass in the upper meter layer amounts to 31.23 metric tons/ha, while in the oak stand, it is 45.77 metric tons/ha. Beneath the spruce stand with oak the bulk of the roots is distributed in the upper 20-30 cm (93.5%); below 50 cm the soil contains only 3.3% of the total root mass. The root distribution in the oak stand is more even. In the upper half meter the root content is 67.2% while in the second half meter, the total root mass is 32.8%, which is ten times more than in the spruce stand. These differences affect not only the

Table 2 — Physical and water properties of soils

Number of experimental plot and forest type	Horizon	Depth, cm	Particle density, g/cm^3	Bulk density, g/cm^3	Total porosity	Maximum hygroscopicity	Wilting moisture
					% of volume	% of dry weight of soil	
1. Spruce with oak-filbert-mixed grasses	A_1	2-10	2.50	1.06	57.6	8.51	11.4
	A_2	17-27	2.52	1.42	43.6	1.15	1.54
	A_2B	30-40	2.58	1.52	41.1	1.19	1.59
	B_1	45-55	2.62	1.57	40.1	3.71	4.96
	BC_{Ca}	85-95	2.64	1.81	31.7	1.98	2.65
2. Goutweed-oak	A_1	5-15	2.51	1.07	57.4	6.12	8.20
	A_1/A_2	20-30	2.54	1.39	45.2	1.53	2.05
	A_2B	32-42	2.57	1.45	43.6	1.80	2.41
	B_1	45-55	2.63	1.51	42.7	3.99	5.35
	BC_{Ca}	70-80	2.64	1.64	37.9	2.41	3.23
	BC_{Ca}	110-120	2.65	1.79	32.4	1.88	2.52
	C_{Ca}	140-150	2.65	1.71	35.5	2.74	3.67

physical properties of the soils but, in particular, their water regime.

A study of the water regime of the soils was made during the 1962-1963 vegetative periods. Soil moisture content was determined monthly in 10-cm layers to a depth of 1 m in five replications. The groundwaters generally do not participate in the accumulation of the soil moisture content and are not lost to transpiration.

The period of observations covered two years which differed sharply in climatic conditions: a wet 1962 and an extremely dry 1963. A total of 482.1 mm of precipitation fell between April and October in 1962 while in 1963 during the same period the precipitation amounted to only 338.4 mm. According to data covering a period of many years the April-October precipitation amounts to 420 mm. The winter of 1962 was considerably warmer with more abundant precipitation than that of 1963. All this had an effect on the moisture content in the soil as well as on the moisture loss.

Observations on the dynamics of soil moisture (Fig. 1) have revealed a general tendency toward decreased moisture content in the soil from spring toward fall. However, the rates of moisture content decrease in the soils by years varied. In the dry year (1963) the soil moisture content for the same number of observations was considerably less than in 1962 (Fig. 2). In June 1962, the soil moisture content to a depth of 1 m was approximately the same in both soils and in 1963 the soil moisture content beneath oak was considerably higher than that beneath spruce. This apparently was due to the fact that more of the June 1963 precipitation penetrated the canopy of the oak forest than that of the spruce.

The autumn dessication in the upper 50-cm layer was approximately the same in both types. In the second half meter the soil beneath the oak was drier than that beneath the spruce.

Summer precipitation generally wets the soils to a depth of 5-10 cm but at individual periods the depth is considerably more. For example, in August-September 1962, with 202 mm of precipitation the atmospheric moisture penetrated the soils to 50 cm. The summer-fall precipitation supplements the moisture content only in the upper 50-cm soil layer and the water penetrates deeper only after the snow melts in the spring. The greatest variations in moisture content are observed in this layer (Fig. 3). The moisture content changes in varying ways between the spring and fall. Beneath the oak stand the fall precipitation replenishes or supplements the moisture content to a considerably great extent, especially in the upper layers. For example, in the upper 50-cm layer of soil beneath the oak stand the moisture content in October 1962 was restored to the level which existed in July. By comparing the fall (1962) and the spring (1963) moisture contents, we see that

Table 3 — Total water loss from a 100-cm thick soil layer in various types of forests (mm of water)

Year	Water content in June	Water loss from the soil	Total precipitation on the soil surface for June-October	Water intake into the soil, October	Water loss	Total water loss from the soil
Spruce stand with oak-filbert-mixed grasses						
1962	299.1	80.4	217.9	23.7	298.3	264.6
1963	240.8	63.1	161.1	37.5	264.2	186.7
Goutweed-oak stand						
1962	258.3	75.1	242.0	68.5	317.1	248.6
1963	277.4	123.2	178.9	8.7	302.1	193.4

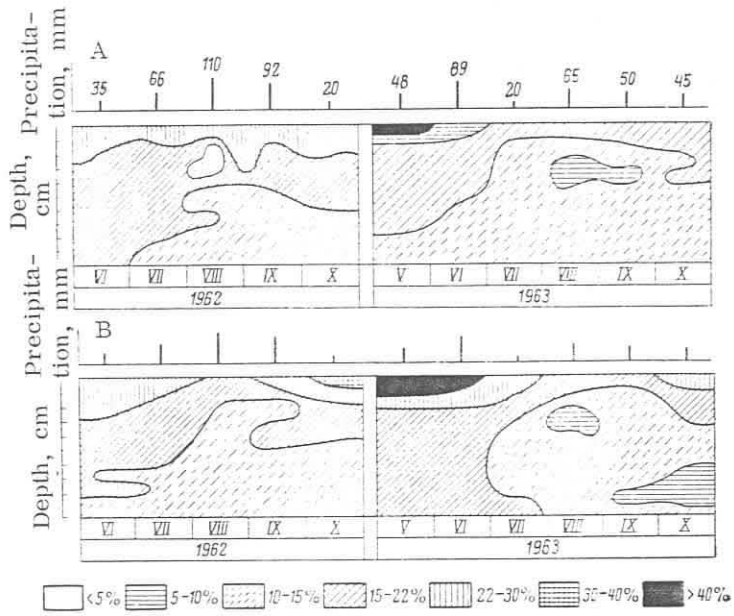

Fig. 1. Chronoisopleths of soil moisture content (% of absolutely dry soil).

A) spruce; B) oak

considerably more precipitation filters through into the 1-m layer of soil beneath the oak stand than into the soil beneath the spruce, which agrees with the data of Zonn and Kuz'mina [2]. Surface runoff was not taken into account in calculating the total moisture loss from the soils (for surface runoff was not observed). The retention of precipitation by crown was assumed to equal 28% for the spruce stand and 20% for the oak. Moreover, it has been shown (Table 3) that from a 1-m layer of soil an oak forest loses more water than a spruce forest.

A comparison of the values of wilting moisture (Table 2) with total moisture has shown that even in the extremely dry year of 1963 the soil moisture content was considerably greater than the wilting moisture.

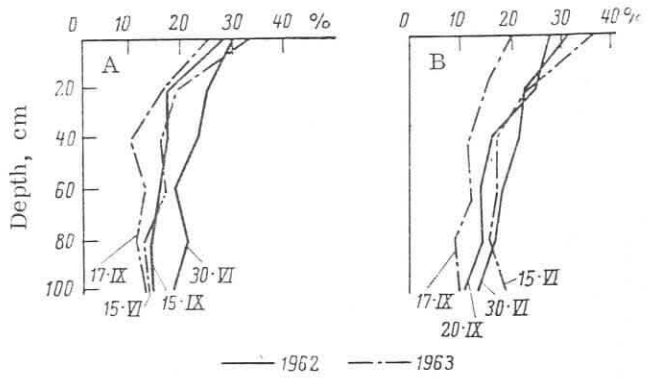

Fig. 2. Change in soil moisture content from summer to fall (% of dry soil).

A) beneath spruce stand; B) beneath oak stand

Table 4 — Dynamics of litterfall in different types of forest (kg of absolutely dry matter per ha)

Experimental plot No. and forest type	Year	Months					Annual total
		July	Aug.	Sept.	Oct.	Nov. - June	
1. Spruce stand with oak-filbert-mixed grasses	1962	252	385	643	1,340	1,775	4,395
	1963	344	542	981	1,545	1,315	4,715
2. Goutweed-oak stand	1962	210	263	820	2,740	1,105	5,128
	1963	185	205	1,245	2,220	1,445	5,400

Table 5 — Dynamics of the litter reserve in different types of forest (metric tons of dry matter/ha)

Experimental plot No. and forest type	Date of determination									
	1962				1963					
	July 12	Aug. 10	Sept. 11	Oct. 12	May 25	June 22	July 24	Aug. 24	Sept. 23	Oct. 23
1. Spruce stand with oak-filbert-mixed grasses	6.2	5.2	4.3	3.6	8.1	7.7	7.0	6.1	5.2	4.5
2. Goutweed-oak stand	4.8	3.4	2.5	1.5	7.0	6.4	5.3	4.1	3.0	2.2

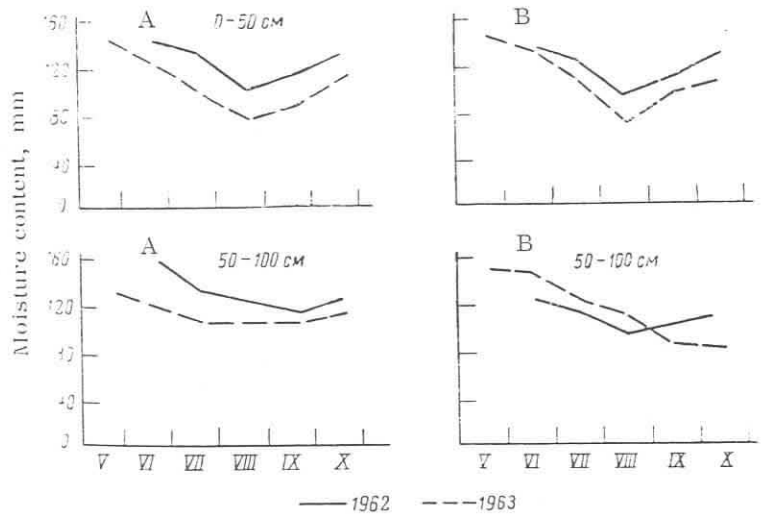

Fig. 3. Moisture content of soils.
A) beneath spruce stand: B) beneath oak stand

As a result, the oak and spruce forests experienced no soil drought even during the years which had most unfavorable moisture.

Differences in the water regime of the soil beneath oak as compared with spruce show more moisture for the soil beneath oak in the spring and summer and greater desiccation toward fall. Beneath spruce the total desiccation is less, as a result of which the moisture and moisture reserve toward the end of the vegetative period in the 100-cm layer are higher than beneath oak. One may assume that the leaching effect of water beneath oak is not increased as compared with the soil of a spruce stand. The differences in the soils beneath the two are obviously not associated with their water regime but are

due to the dissimilar rate in the cycles of substances.

The differences in the influence of the tree tops can be most clearly seen in the annual litterfall on the soil surface. Two years of observing the dynamics of litterfall accumulation (Table 4) show that there is considerably more litterfall for the oak stand than for the spruce. Judging from the pH values for the A_0 horizon (Table 6) the litterfall and litter of a spruce forest is considerably more acidic than that of oak. This directly implies that the litterfall of oak is richer in bases and that, unlike the spruce, the oak stand extracts ash elements more intensively into the biological cycle.

Basic differences are observed in the quantity and dynamics of the litter (Table 5). Considerably more litter is accumulated beneath spruce than beneath oak. The difference in the decrease of forest litter during July-October in 1962 was 3.3 metric tons per ha for oak and 2.6 metric tons/ha for spruce with oak. The difference in the litter decomposition rates can be seen even more clearly by comparing the 1963 data. During the vegetative period (May-October) the litter reserves in a spruce stand decreased by 3.6 metric tons/ha while in an oak stand the litter reserves decreased by 4.8 metric tons per ha. The litter decomposition rates in 1962 and 1963 were almost the same when compared over the same periods of time. The differences in the intensity of litter decomposition in an oak and spruce stand are confirmed by the data on the liberation of CO_2 from the surface of the soils of both plantations (Fig. 4). The CO_2 liberated from the soil beneath the oak is considerably higher than that beneath the spruce, especially during the summer months.

These data enable us to assume that the biological activity, which is expressed in the high rate of litter decomposition and intensity of the biological cycle of matter, is considerably greater in the soil influenced by oak than that of spruce. This is also shown by certain data which describe the physico-chemical properties of the soils (Table 6).

There is less humus in the soil under oak stand than in the soil under spruce stand, which is associated with the more rapid mineralization of the organic residue. The more even humus distribution throughout the profile is determined by the high mobility of humus in the soil. The humus accumulation

Table 6 — Certain physico-chemical properties of soils

Experimental plot No. and forest type	Depth, cm	Exchangeable cations, meq				Total	% of total				Nonsaturation, %	Water pH	Humus content, % (after Tyurin)	Nitrogen content, % (after Golubev)	C:N	CO_2 of carbonates, %
		Ca^{++}	Mg^{++}	Al^{+++}	H^+		Ca^{++}	Mg^{++}	Al^{+++}	H^+						
1. Spruce stand with oak-filbert-mixed grasses	0.2	Not determined			—	—	—	—	—	—		5.0	70.70*	1.65	24.9	Not det.
	2.10	4.8	1.2	1.8	0.7	8.5	56.5	14.1	21.1	8.3	70.6	4.2	7.0	0.34	12.0	Not det.
	17-27	2.0	0.6	0.3	0.1	3.0	66.5	20.0	10.0	3.5	86.5	5.5	0.90	0.11	4.7	Not det.
	30-40	2.6	0.6	0.1	0.1	3.4	76.5	17.7	2.9	2.9	94.2	6.0	0.45	0.08	3.3	Not det.
	45-55	7.0	2.8	None		9.8	71.4	28.6	2.9	None	100	7.1	Not determined			0.1
	85-95	Not determined				—	—	—	—	—	—	8.1	Not determined			11.0
	130-140	Not determined				—	—	—	—	—	—	8.6	Not determined			11.2
2. Goutweed-oak stand	0-1	Not determined				—	—	—	—	—	—	5.8	69.9*	2.17	18.6	Not det.
	5-15	3.3	0.9	0.8	0.6	5.6	59.0	16.1	14.3	10.6	75.1	5.5	3.90	0.22	10.3	Not det.
	20-30	3.6	0.6	0.2	0.1	4.5	80.0	13.3	4.4	2.2	93.4	6.2	1.26	0.13	5.6	Not det.
	32-42	5.4	1.0	None		6.4	84.5	15.5	None		100	6.9	0.47	0.10	2.7	Not det.
	45-55	10.9	1.7	None		12.6	86.5	13.5	None		100	7.7	0.39	0.04	5.5	0.2
	70-80	12.4	5.9	None		18.3	67.9	32.1	None		100	8.2	Not determined			8.3
	140-150	Not determined										8.4	Not determined			10.9

* Ignition losses

in the soil under spruce is limited to the upper horizons and decreases sharply with depth. Such a humus distribution is typical of the Sod Podzolic soils. The ratio C:N in the humus accumulative horizon of the soil of an oak stand is narrower, which indicates that its organic matter is greatly enriched with nitrogen and has a higher degree of organic matter humification than the soil of a spruce stand.

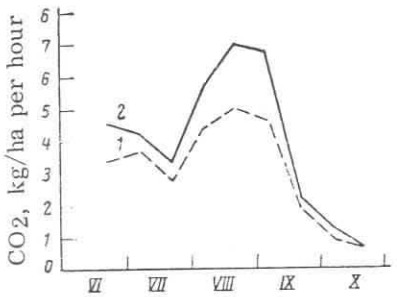

Fig. 4. CO_2 loss from the soil surface during various periods of vegetation, 1963.

1) spruce stand; 2) goutweed-oak stand

The distribution of the exchangeable cations reflects both the degree to which the soils are deficient in the clay fraction as well as the biogenic accumulation associated with an accumulation of litterfall and the rate of its decomposition. There are fewer exchangeable bases in the soil under oak stand than in the soil under spruce, because of the lower humus content in the humus accumulative horizon. The soil under oak stand does not have a horizon which is severely depleted in exchangeable cations as is the case with the A_2 horizon of the soil under spruce stand. The soil beneath an oak stand differs basically from the soil beneath a spruce stand with oak by the character of distribution of the exchangeable bases. A sharp increase in the exchange capacity at a depth of 45-55 cm is associated with a finer texture and with the carbonates of the lower-lying horizons.

Calcium is predominant in the composition of the adsorbed bases in both soils. The content of exchangeable Mg in per cent of the total exchangeable bases increases with depth. There is more adsorbed H and Al in the soil under spruce than in the soil under oak, which explains why in both cases exchangeable Al is predominant over exchangeable hydrogen. A higher degree of base saturation in the soil under oak as opposed to that of spruce agrees with the pH values. The litter and soil under oak in the upper horizons are characterized by a weakly acidic reaction while the soil under spruce stand is clearly acidic. In both soils the acidity decreases with depth but the reaction is more acidic in the A_1 and A_2 horizons of the soils under spruce.

These data show the basic differences between the soil under spruce and that under oak. If the podzolic process in the soil under spruce stand is clearly developed, it is not apparent in the soil under oak. The soil under oak stand is closer in its properties to the group of Brown Forest soils than to the group of Sod Podzolic soils.

Inasmuch as the soil under oak forest and the soil beneath a spruce stand with oak are formed under similar climatic and geological conditions, the differences between them, it seems, should be only the influence of the tree stand. In summarizing the results, we may conclude that soils, formed in Lithuania on binary deposits beneath oak differ sharply in dynamic processes and certain physical and physico-chemical properties from the Sod Podzolic soils and are closer to the group of Brown Forest soils. Some authors are inclined to assign such soils to the Sod-calcareous (residual) soils, which seems to us also to be incorrect, since the upper layer of the soil did not contain carbonates and their leaching was extremely limited.

It seems to us that the problem of the difference in soil formation beneath spruce and oak stands in the northwestern USSR is of great genetic and productive importance, but ~~which~~ has not been sufficiently treated to date.

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